A low-cost high-quality system for the acquisition and digital processing of images of WEFAX type provided by meteorological geostationary satellites

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A TECHNICAL NOTE ON A LOW-COST HIGH-QUALITY SYSTEM FOR THE ACQUISITION AND DIGITAL PROCESSING OF IMAGES OF WEFAX TYPE PROVIDED BY METEOROLOGICAL GEOSTATIONARY SATELLITES

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ABSTRACT

A low-cost high-quality system for the processing of satellite data received in the WEFAX analogue format is presented. It is composed of a receiver with its antenna connected to a personal computer with digitizing and graphic boards. The software performs automatically storage of data onto the harddisk, contrast enhancement and false colors display, accurate navigation and animation loops. Interactive features are also available. Such a system is of great use in meteorological education, in weather forecasting and in environmental research. Taking into account the peculiarities of the WEFAX format, some algorithms have been devised to correct for the atmospheric depletion. Ground albedo can therefore be accurately evaluated on a pixel basis as well as global irradiation, cloud coverage and atmospheric global transmission.

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1. INTRODUCTION

Satellite images are widely used to support meteorological studies and related topics. Of particular interest for european individuals and bodies is the Meteosat system, which monitors the african and european continents and the surrounding oceans (Anonymous, 1978 ; De Waard *et al.*, 1984). In addition to meeting the needs of the european meteorological services, it represents the european contribution to two programmes set up by the World Meteorological Organisation : the World Weather Watch and the Global Atmospheric Experiment.

The raw image data from the spacecraft are transmitted on a line by line basis to the controlling ground station where they are processed for correction of minor defects and optical or calibration errors and for navigation (Jones *et al.*, 1980). A further function of the Meteosat system is the distribution of earth images and other meteorological information by use of the satellite itself as a relay. Two forms of transmissions are used : high-resolution data, utilised by Primary Data User Stations (PDUS), and analogue data in WEFAX (WEather FAC-Simile) format, received by Secondary Data User Stations (SDUS).

Given the importance of the knowledge of the weather and climate, the quality of the Meteosat images, their availability and their access free of charge make them very attractive to a large number of bodies and even individuals. Such demand has led to the availability of a number of SDUS which are cheaper by far than the PDUS and are affordable by bodies with limited funds, such as most of the universities. An even cheaper means to receive Meteosat data has been described by Sanderson (1988). It makes use of the terrestrial meteorological broadcasts of images made by the national meteorological agencies. However, some limitations on the image quality and the dissemination schedule often make SDUS more attractive. Analogue data displayed onto a screen after a bulk digitization as available in SDUS are certainly of interest for educational purposes (see *e.g.* "EARSeL News", 1986(a), 1986(b) ; Becker, 1989), but do not present a high enough quality for scientific research purposes.

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The goal of this technical note is mostly to present a converter which reads the analogue data output from a SDUS and converts them into digital data to be stored on the harddisk of a personal computer. It has been designed to meet the demands of *CTAMN - Ecole des Mines de Paris*, which asked for a low-cost and low-noise system to permit the use of SDUS in quantitative estimates of meteorological or related parameters.

A complete system was realized, which comprises :

- a SDUS of any make ;
- a personal computer (PC) IBM compatible ;
- the analogue/digital converter to be installed into the PC ;
- a PC graphic board to display colour maps (many standards are supported) ;
- a software for the data acquisition and the management of the system and providing also some features in image processing.

The software and the converter were designed by *CTAMN - Ecole des Mines de Paris* and its partners. Available since 1985, they have been utilised extensively for research studies. They are now described.

2. DESCRIPTION OF THE A/D CONVERTER AND OF THE SOFTWARE

The meteorological geostationary spacecrafts have one or more dedicated channels operating at about 1,700 MHz, which are used to distribute conventional analogue transmissions of WEFAX type. Usually the receiving systems are designed to receive both signals at 1,700 MHz and signals at about 137 MHz coming down from the sun-synchronous NOAA or METEOR satellites (APT format). Hence they comprise a device which converts the 1,700 MHz signal into a 137 MHz one. As an output, these systems provide an analogue signal with a 2,400 Hz sub-carrier. This audio signal can be recorded on an audio-cassette recorder.

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The analogue/digital (A/D) converter is a single board to be plugged into one of the slots of the bus of a personal computer IBM-PC compatible. It comprises two parts. The analogue part is mostly composed of bandpass and low-pass filters and of a demodulator made by Analog Device. The demodulated signal is sampled and digitized using a 8 bits processor Intel 8085. The processor also identifies the particular sequences heralding beginning or end of emission and of image as well as the image line synchronization. Once a line processed in 125 milliseconds, the 8085 processor hands the data to the PC processor (8086 or 80286 or 80386) through the bus. The latter writes the processed line onto the hardisk while the former is processing a new line. The converter comprises some trimmers which can be tuned in order to get the best signal and also to fit precisely the converter clock to the satellite transmission inner clock. It is connected to the FM receiver by the mean of a simple audio cable with RCA connectors.

It has been tested in a large number of PCs of different brands, ranging from PC/XT (processor frequency : 4.77 MHz) to the most powerful PC/386 with a processor frequency of 25 MHz. Harddisks, hardcards and filecards, from low to high speed access, have also been tested as well as buses which frequency is greater than the PC/AT standard (8 MHz). It has been concluded that only bus frequencies strictly greater than 10 MHz do create malfunctionning. Such frequencies are quite rare at the moment of writing and using the converter with such buses will require replacing some of its components by adapted ones, if available.

The signal-to-noise ratio S/N found in the images stored in the computer was used to evaluate the quality of the whole hardware system. This ratio was computed using structure functions (see *e.g.* Curran and Dungan, 1989, or Wald, 1989). Of course, the values presented below depend greatly upon the gain of the antenna, that is mostly dependant of its diameter. A procedure for the calculation of the figure of merit G/T, which is the ratio antenna gain to total system noise temperature, is described for example by Beni (1989) and gives typical values for the Meteosat S-band SDUS. Some key design parameters for the receiving system are presented by Beni,

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which permit rapid determination of the best compromise between the ground antenna gain and receiving system noise figure values. In brief, the largest the antenna, the greatest the ratio. For trial the converter was connected to a SDUS with an antenna of 1 m in diameter produced by the Wraase company. Similar calculations were made at the same time using an old-designed high-quality SDUS of CIT-Alcatel brand, comprizing an antenna of 1.5 m in diameter and a rather massive converter device. Averages signal-to-noise ratios were 11.6 along a line, and 3.8 along a column for the hardware of CIT-Alcatel for a mean signal of 80 counts, and were 9.1 (line) and 7.6 (column) for the present converter. It demonstrates that high-quality is offered by the present converter which S/N presents less difference in both dimensions than the oldest hardware.

Software is based upon the Minimage software library for image processing which has been developed at *Centre de Télédétection et d'Analyse des Milieux Naturels (CTAMN)* of *Ecole des Mines de Paris*, in Borland Turbo-Pascal for PC (Anonymous, 1989). Therefore it is fully compatible with the Minimage-related commercially-available softwares for general purposes and remote sensing images processing. It can run in a fully automated fashion, which can be overrided by an operator at once. The software offers many features which, briefly speaking, are : scheduling acquisition and doing it, display after contrast enhancement, navigation and animation loop. Non automatic features are also offered : display of any previous image still stored onto the disk (up to 15), colour table interactive editing by adjusting independantly Red, Green and Blue channels, magnification, instant display of the pixel value and image coordinates with mouse clicking, profile extraction and display (curve and values), interactive constrast enhancement using linear or isopopulation or gaussian stretching, animation of a previous loop already stored (up to 99).

Meteosat images are accurately navigated before dissemination (Jones *et al.*, 1980). However the digitizing board does not take always the same time to recognize the beginning of the emission, the phasing and the synchronization signals. This is also true for most of the SDUS digitizing

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the signal for low-quality video. Therefore, successive images of a same area are not geometrically superimposable. Differences in location between two images are constant within the whole area and amount to a few lines and columns. Once some remarkable points, such as the crossings of latitude and longitude or other landmarks registered by the operator using a single image and stored into an ancillary file, the differences in location are computed by a maximum cross-correlation search technique. These crosses are inserted in the image by the European Space Operations Center. To take care of the presence of the clouds, only correlation coefficients greater than 0.7 are accepted. This value results from about three years of experience with daily acquisition of such images. The modes of the histograms of the differences in line and row are then computed and used to correct the geometry of the image. Similar operations are made for GOES.

Regarding the japanese geostationary meteorological satellite, the situation is different because the satellite operating organization does not navigate the images before dissemination as precisely than its european counterpart. Therefore they are not superimposables. Differences in location between two images are not constant within the whole area and usually increase with distance to Japan. In that particular case, a first-order polynomial model can take into account these variable differences. It is statistically estimated from the landmarks using a least-square technique and then applied to the image to navigate it.

3. SOME APPLICATIONS

Provided the rule converting the high resolution digital data flowing from the satellite into the analogue disseminated signal is not very often modified by the satellite operator (see for example Moussu *et al.* for the case of Meteosat), the converter is useful not only for permitting digital processing, but also because the quality of the data it delivers allows quantitative estimates in meteorology and related topics. The described converter has been in use since about 1985 at *CTAMN - Ecole des Mines de Paris*. Previously an old-designed and expensive converter from CIT-

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Alcatel was used since 1980. Such converters made possible some studies which were mainly based on the quantitative analysis of time-series of Meteosat images. Some of them are now briefly presented mostly to illustrate our saying rather than to discuss them since their results have already been published.

Some years ago, in summer, a flight campaign took place in the Southwest of France, covering a very wide area of a few tens of thousands of sq km. Measurements over the 1 m size pixel were made in near infrared range, imposing the plane to fly by night. Meteorological observations and particularly cloud cover are available at local small airports, but only during office hours. The last observations were given at 6 p.m. while flights were made in the middle of the night. Hence it was impossible to know which part of the area was cloud-free and to decide to overfly it or not. This difficulty was overcome by processing Meteosat images from our SDUS. They were scrutinized carefully to follow the clouds displacements and particularly to analyse the development of the convective clouds occuring in summer in that part of France. Hence we were able to predict at the end of the afternoon which part of the area will be cloudfree at night, a few hours later. The mission was a real success, and lasts only two months.

Such an operation mostly makes use of the possibilities of basic image processing techniques offered by a computer, such as magnification, contrast enhancement and geolocation. Another very recent exemple is provided by the explosion and fire of the oil tanker Mega-Borg, in the Gulf of Mexico, June 8, 1990. Most of the oil burned, was collected, evaporated or dispersed, but an estimated spill of about 16,000 tons threatened the Texas shore. The present system was used during this crisis, in order to analyse the images of the atmosphere and ocean surface provided by GOES. Ocean circulation was inferred from the sea surface temperature images and cloud movements and developments were examined in close relation with conventionnal meteorological observations to provide weather short term predictions. All these informations were used to assist experts and also to help forecast of the oil spill behaviour by a numerical model.

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Wald and Monget (1983a) demonstrated that analysis of the shapes of the sea sunglint provides information about the wind speed at the surface of the sea. They developed an easy-to-implement algorithm applying to WEFAX images from polar orbiting NOAA satellites. However its application to meteorological geostationnary satellites is restricted to the tropical area because of the location of the satellites with respect to the sun (Wald, Monget, 1983b).

The mapping of the global solar radiation at ground level from satellite observations has been the major study made using such WEFAX images and leads to the realization of the system now discussed. This research programme, known as the "HELIOSAT" programme, involves three goals : cloud detection, ground albedo mapping, and atmospheric global transmission estimation. Briefly speaking, the Meteosat counts are divided by the spectrally integrated solar irradiance which would be measured by the sensor after it has been reflected on an horizontal plane located at each pixel under clear sky, that is a sky for which the direct component of the light is much larger than the diffuse one. This ratioing is detailed in Moussu *et al.* (1989), and is similar to the computation of the albedo of the ground if the sky is clear or of a mixed signature involving the ground albedo and the albedo of the atmospheric column over the current pixel (apparent albedo). A cloud cover index is derived at each pixel making use of the albedos of the ground and of the clouds and of the apparent albedo. This index has been shown to be linearly related to the total atmospheric transmittance (Cano *et al.*, 1986 ; Diabaté *et al.*, 1988) and is subsequently used for the estimation of the global radiation at ground level. An operational tool using the present converter and a dedicated software has been realized (Diabaté *et al.,* 1989-a) and is now commercially available together with the present product. Beyond atmospheric transmittance and solar global radiation, the method provides maps of the ground albedo. Diabaté *et al.* (1989-b) use such maps to monitor the vegetation and its changes in Sahel during a complete year. The authors depict the main patterns and the temporal variations of the albedo with respect to the vegetation types. They confirm the great spatial variability of the vegetation

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growth rate which is correlated to the variability of the rainfall. Such maps are also are the basis of the observations of the decrease of Lake Chad (Wald, 1990) and reveal the functionning of the lake as well as the large variability of the open water areas during a year.

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